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Published in:
Polymer Process Engineering 09

Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):
Islam, A., Hansen, H. N., & Jørgensen, M. B. (2009). 2k micro moulding for MID fabrication. In *Polymer Process Engineering 09: PPE-Enhanced polymer processing* (1 ed., Vol. 1, pp. 273-293). University of Bradford.

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Two component injection molding for MID fabrication

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Molded Interconnect Devices (MIDs) are plastic substrates with electrical infrastructure. The fabrication of MIDs is usually based on injection molding and different process chains may be identified from this starting point. The use of MIDs has been driven primarily by the automotive sector, but recently the medical sector seems more and more interested. In particular, the possibility of miniaturization of 3D components with electrical infrastructure is attractive. The paper describes possible manufacturing routes and challenges of miniaturized MIDs based on two component injection molding and subsequent metallization. This technology promises cost-effective and convergent manufacturing approaches for both macro and micro applications. This paper presents the results of industrial MID production based on two component injection molding and discusses the important issues for MID production that can modulate the qualities of final MID. Results and discussion presented here can be a valuable used guide for mass production of molded interconnect devices.

Keywords: Two Component Injection Moulding, Selective Metallization, Moulded Interconnect Devices.

Introduction

MIDs are defined as injection moulded plastic parts which incorporate circuit patterns and integrate mechanical and electrical functionalities on a single device [1]. The technology contains huge possibilities for many applications in micro electro-mechanical systems because of its potential of reducing the number of components, process steps and finally in miniaturization of the final product [1]. MIDs have already found huge application areas in electronic communication and in automotive industries. At present almost 80% of the mobile phone

antennas are produced by MID technology [2]. There are many automotive applications for MIDs, which vary from sensor systems to centralized door locking mechanisms. MIDs are being used in automotive dashboard, steering wheel, turbocharger regulator, seat belt adjuster and sun hood opener. Aerospace and consumer industries are also aware of the advantages of MID technology and they are introducing more and more MIDs in different components of their products. A relatively new area opening for MID technology is the health care industry where miniaturization of products and components is an ever increasing trend. MID technology is already being used by Siemens in their hearing aid microphone connector. KaVo Dental GmbH has introduced a new device to detect tooth decay using MID technology [2]. In the near future more and more health care devices and instruments will be redesigned to benefit from the advantages offered by MID. This paper demonstrates how the MID technology can be used for industrial products to achieve shorter process chain, reduced number of components and assembly operations. An existing hearing aid on-off switch (made by SONION A/S) is used as a reference product. The results and discussion presented in this paper suggest that the existing on-off switch can potentially be replaced by new MID technology in a cost effective way.

Available Process Chains for MID

There are various combinations of process chains for producing MIDs. Almost all MID production starts with injection moulding of the plastic substrate. Two other prime process steps are circuits structuring and selective metallization on the activated plastic surface. Figure 1 shows possible ways for manufacturing MIDs. Among the listed process chains the Laser Direct Structuring process (1a in Figure 1) and Two Component Injection Moulding (2b in Figure 1) are two of the most industrially adaptive processes used for high volume production.

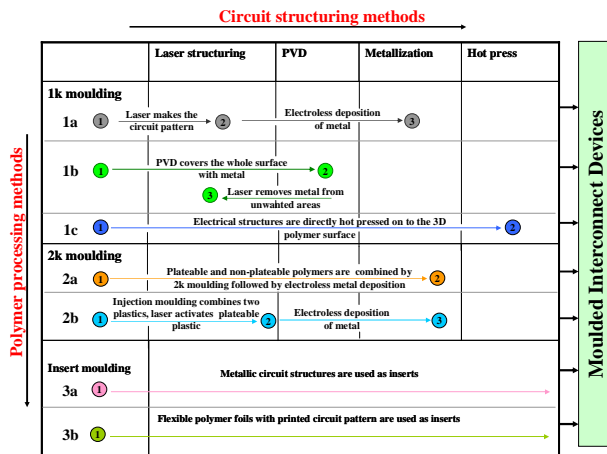


Figure 1: Illustration of combinations of process steps for the manufacturing of MIDs [3].

Among other emerging MID process chains Thermal Spray, Flamecon and MIPTEC techniques have potential for industrial applications [2]. In Thermal Spray process, metal particles are melted by heat and subsequently sprayed on the plastic substrate, so the circuit tracks are built by a thermo-kinetic process [2]. The Flamecon process use plasma printing for metal deposition on the substrate [2]. The MIPTEC process uses laser on a metallized substrate to disconnect the circuit area from the bulk area. Then the circuit area is connected to the electroplating bath to grow metal only on the circuit and afterwards metal is removed from the bulk area by etching [2]. The following section describes the demonstrator MID fabrication by two component (2k) micro injection moulding. The process chain chosen for the experiment is shown in Figure 2.

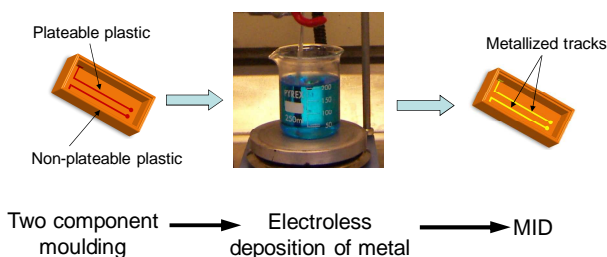


Figure 2: Illustration of MID production process by 2k moulding and subsequent selective metallization of polymer.

Experimental

The objective of this experimental investigation is to gain in-depth knowhow about industrial MID production by two component injection molding and to find critical parameters that can affects the quality of final MID

products. The objective also includes finding suitable material and geometrical constrains for MID product design.

The 2k parts for these experiments were produced by cavity transfer process. First shot parts were produced in one cavity of the mould during first shot. And in the second shot these parts were over moulded with another material in the second cavity of the mould.

Materials and method

For the investigation on the bond strength of two different plastic materials a 2k tensile bar test geometry (shown in Figure 3) was used. And for demonstrator MID fabrication test geometry was chosen from an industrial product (discussed later).

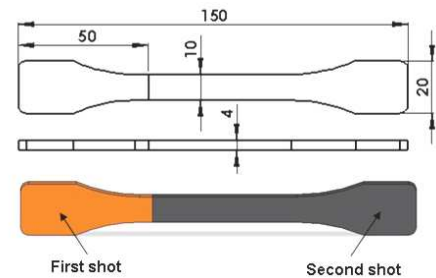


Figure 3: 2k tensile bar geometry (made of two different polymers- standard geometry for tensile testing equipment).

Table 1: List of plastic materials used in the experiments.

Name	Abbreviation	Trade name	Grade	Manufacturer
Polyetherimide	PEI	Ultem	1000	GE
Polyetherimide	PEI	Ultem	2312	GE
Polyetheretherketone	PEEK	Victrex	150GL30	Victrex
Polyphenyleneether blends	(PPE+PA+GF)	Noryl	GTX810	GE
Acrylonitrilebutadienestyrene	ABS	Terluran	997VE	BASF
Polycarbonate	PC	Lexan	500R	GE

Results and discussion

Two important issues for MID production by 2k moulding is polymer-polymer bonding and polymer-polymer interface quality. Experimental investigation shows polymer-polymer bonding in 2k moulding is governed by many factors listed in the Figure 4. Detail discussion about the factors and their influence can be found in reference [1].

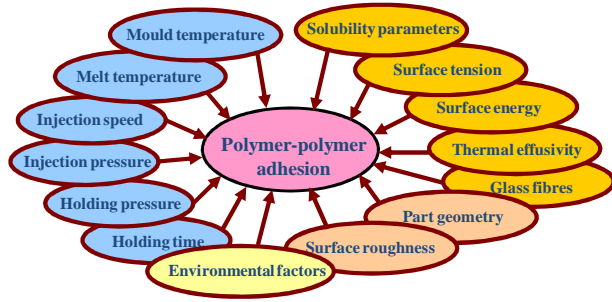


Figure 4: Factors influence polymer-polymer bonding during 2k moulding [1].

Besides the above mentioned factors material shot sequence in 2k moulding (which material is being moulded first) makes a big difference in the bonding of the two materials. Figure 5 shows the bond strength of different material combinations as a function of their shot sequences found in the experimental investigation. This phenomenon can be explained by the interface temperature between the first shot inlay part and the send shot polymer melt during 2k moulding [1]. For a reasonably good adhesion, the interface temperature should be high enough so that the two polymers can melt together and can make a bond at the interface. In absence of high enough interface temperature, no bonding will take place between the two polymers.

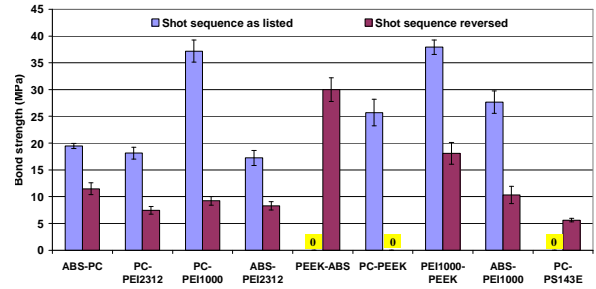


Figure 5: Bond strength of two different plastic materials as a function of shot.

One important aspect of 2k moulding is the relation between polymer-polymer bond strength and interface between two materials. For successful MID sufficient bonding between the two materials is required on the other hand a sharp and well-defined interface is also required for complete selectivity in the metallization process. A comparative analysis between the interface study and the polymer-polymer bond strength investigations (conducted by the authors and presented in reference [1]) reveals a dilemma between the two aspects of quality parameters for 2k moulded plastic parts. Figure 5 shows that the bond strength between PC and PEEK is 26 MPa when PC is moulded in the first shot and same material combination has bond strength of 0 MPa when the shot sequence is reversed (PEEK in the first shot). And the interface study shows that this material pair has a better interface quality when PEEK is moulded first [1]. It means that the shot sequence which has poor bond strength yields a sharp and well distinguishable interface of the two polymers. The same observation has been made with PEI and PEEK combinations.

When a polymer pair has a weak adhesion, the interface contains a gap (clear separation line with cracks) of several micro meters between the two polymers. This micro gap between the two polymers makes the boarder sharp and distinguishable after injection moulding. But when two polymers adhere strongly, the gap between the two materials is reduced or disappears (Example of PEEK-PC material combination in presented in Figure 6).

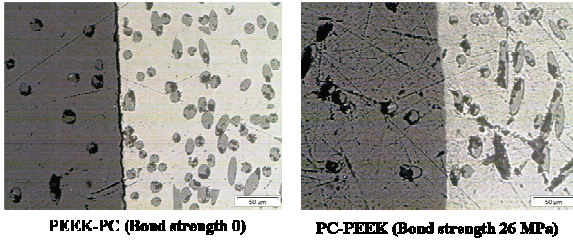


Figure 6: Interface pictures of PEEK-PC and PC-PEEK shot sequences (on the left picture the interface contains a gap of several μm between the two materials and has no bond strength on the other hand the gap disappears at higher bond strength in the reverse shot sequence).

For stronger bonding of two polymer, the interface temperature during the second shot should be so high that the surface of the inlay part (first shot) is melted and two polymers can mix together [2]. On the other hand, for geometrical correctness and interface quality of two 2k part, the inlay part should withstand the heat and pressure of the second shot melt, so that it can retain its shape and keep the geometry undistorted. In the experimental case, heat deflection temperature (HDT) of PC is lower than PEEK (HDT for PC and PEKK are 146°C and 315°C respectively). When PEEK is used as first shot material, it can withstand the injection moulding condition of second shot PC so the interface is well-defined, whereas the bond strength is poor due to the insufficient melting and mixing of the two polymers. In the reverse shot sequence (PC first shot and PEEK second shot) the two polymers can melt together and achieve a stronger bonding but the geometrical features of the inlay PC are destroyed due to its poor thermal and mechanical properties, during the second shot injection of PEEK. The same explanation is valid for other material combinations presented in Figure 5. Investigations on the bond strength of two polymers also show that higher process settings in the injection moulding machines facilitate the bond strength between two polymers [1]. On the contrary higher settings of injection moulding parameters destroy the inlay geometry and affect the sharpness of the interface negatively [1]. Finally it can be concluded that the requirements for good interface quality of two polymers are opposite to the requirements for higher interfacial adhesion between the two polymers and this is the dilemma between polymer-polymer interface quality and polymer-polymer bond strength. So the material shot sequence, injection moulding process condition for 2k moulding should be customized according to priority of bond strength or interface quality.

Industrial case study: Demonstrator MID Fabricated by 2k Moulding

This section presents discussion and experimental results on fabrication of a demonstrator MID by 2k moulding technique. To demonstrate the advantage of using MID technology compared to conventional technology a standard on-off switch used in hearing aid was chosen as a reference product. The current on-off switch produced by SONION A/S for hearing aid instrument is shown in Figure 7. The maximum diameter of the existing switch is 2.5 mm and the height without terminals is 3.5 mm. It consists of seven different components and involves eleven different assembly steps.

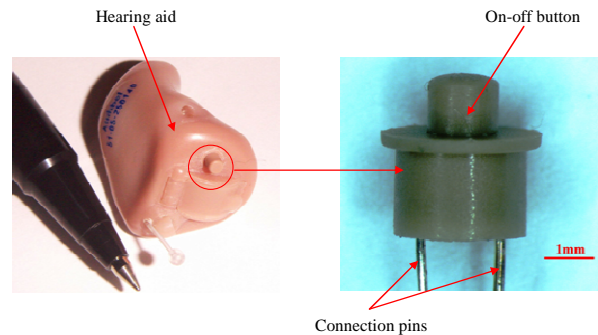


Figure 7: On-off switch connected with the hearing aid (left) and close up view of one on-off switch (courtesy of SONION A/S).

New Concept of On-off Switch Based on MID Technology

A concept of an alternative on-off switch based on MID technology is presented in the right picture of Figure 8. As shown in the figure the new concept is based on mainly three components: core, house and dome. The most technical part of the new concept is the core which is a two component injection moulded part. It combines two different plastic materials, one of which is suitable for electroless metal deposition, thereby creating the conductive tracks. The housing part provides the encapsulation for the whole part and holds the dome on the top of the core. The dome is made of electrically conductive flexible rubber (rubber filled with carbon black or silicon rubber) and when it is pressed, it connects the two ends of the metallic tracks, so that the current can flow through the circuit.

The house and the dome of the on-off switch can be realized by conventional injection moulding process. The only MID component in the new concept is the core. The fabrication of the demonstrator on-off switch core is described in the following section.

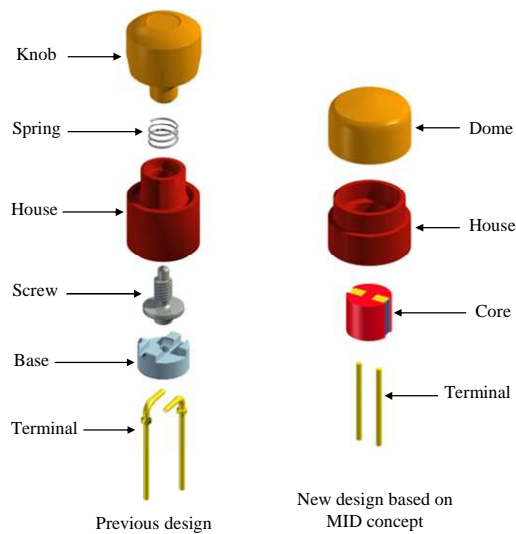


Figure 8: Components of the existing on-off switch (left). Components of new on-off switch based on MID (right).

Core fabrication by 2k MID technology

The chosen process chain for on-off switch core is two component injection moulding and subsequent selective metallization. The final test geometry is the core of Figure 8 with some modification in dimensions and features. The over all size was made bigger considering the manual handling of the part in injection moulding by cavity transfer process. Two through holes were added to the design to test through hole plating, and also to connect the core with an external circuit. In addition to this, several sharp corners were introduced in the design to mimic the filling difficulties in micro injection moulding, to create some mechanical locking between the two polymers and also to check metallization on the sharp corners of the metallizable polymer. Figure 9 shows the geometrical specifications of the 2k core used as test specimen.

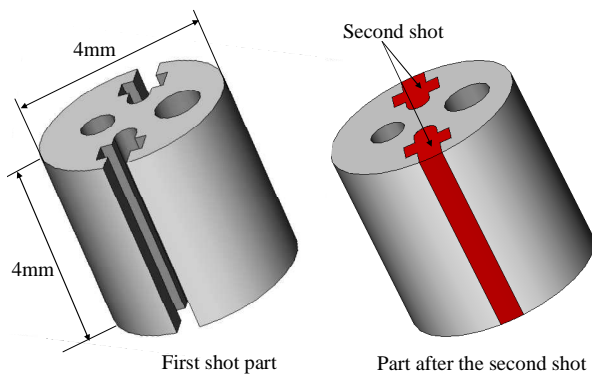


Figure 9: 3D view of the on-off switch core. First shot part (left). The part after second shot (right).

A flexible mould was designed to injection mould the 2k part. An already existing mould block was used for this purpose. The final tool inserts were produced by EDM milling. To injection mould the two component core, an Arburg 320S allrounder injection moulding machine placed at the Plastic Centre of SONIAN A/S was used. Ultem PEI1000 and Noryl GTX810 plastic materials (new material combination suitable for selective metallization found in the previous work [3]) were applied with the recommended injection moulding conditions. After injection moulding of the first shot parts with Ultem PEI1000, the insert from the mould was replaced with the second shot insert. The previously moulded parts were placed in the mould cavity and was over moulded with the second polymer (Noryl GTX810) to complete the two component part geometry. After injection moulding the parts were used in metallization using the recipe adopted from reference [5]. Finally, electrical testing was carried out on the metallized parts to check their suitability for actual applications.

Quality inspection and functionality test

The newly designed and manufactured tool inserts proved successful in the injection moulding operation. The first shot parts, both with Ultem PEI1000 and Noryl GTX810 were injection moulded with complete filling of the cavity and without any difficulties associated with the part ejection. During the second shot, Ultem PEI1000 part were over moulded with Noryl GTX810 to complete the two component part geometry. Figure 10 shows the two component push button part moulded with Ultem PEI1000 and Noryl GTX810.

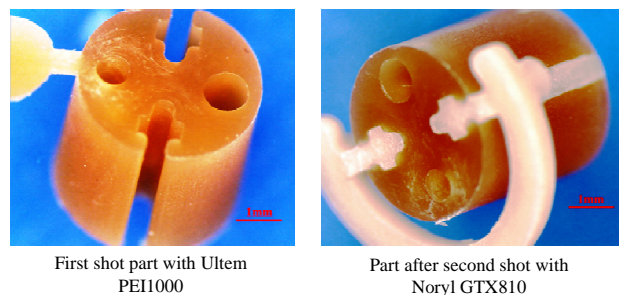


Figure 10: Injection moulded first shot part (left), part after second shot (right).

The metallization of the two component parts was completely selective where only Noryl GTX810 was coated with copper, and there were no traces of copper deposition on the other polymer. Figure 11 shows the selectively metallized 2k core where Noryl GTX810 has

been metallized and Ultem PEI1000 has not been metallized. Metallization on the sharp corners and different critical sections of the part was also selective.

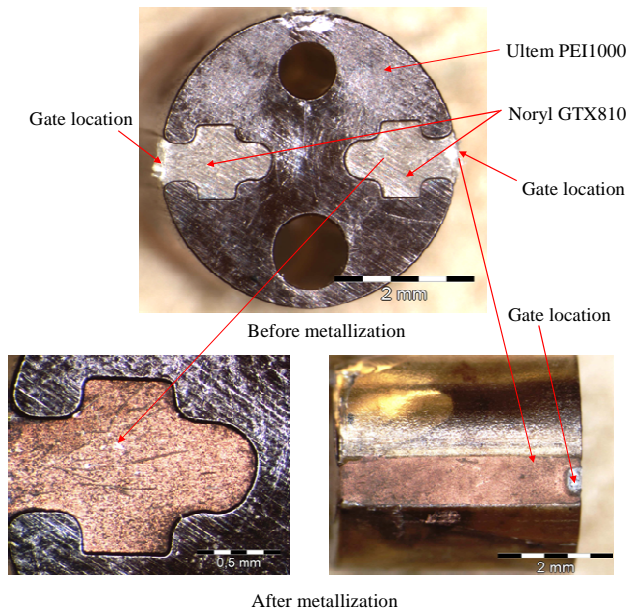


Figure 11: Selectively metallized 2k on-off button core.

To investigate through hole plating, first shot parts moulded with Noryl GTX810 were metallized. Figure 12 shows the different sections of a metallized part. The outer surface of the part is completely metallized. But the through hole plating proved to be a big challenge for MID.

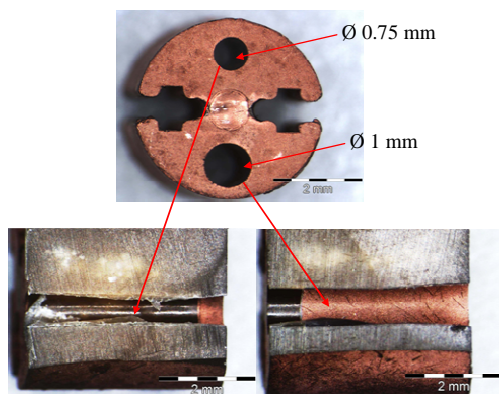


Figure 12: Through hole plating of first shot part moulded with Noryl GTX810 plastic.

The hole with a diameter of 1 mm has been metallized on the inner wall through a longer distance than the hole with a diameter of 0.75 mm. The bigger hole has an aspect

ratio (length/diameter) of 4 and the smaller hole has an aspect ratio of 5.3. The through hole plating result shows that metallization inside a through hole is difficult especially when the hole aspect ratio is high. The reason for this is the trapped air or hydrogen bubbles inside the narrow channel of the through hole during metallization. This result suggests avoiding through holes in plateable parts of the MIDs if possible. Where a through hole is prerequisite, the length to diameter ratio of the hole should be below 4. Otherwise, the plating setup should be optimized to avoid trapping of air or hydrogen bubbles.

For the final application of MIDs, conductivity of the metallized parts is an important characteristic. A demonstrator circuit consisting of a selectively metallized on-off switch core, electric bulb and power source, was set up. Figure 13 shows the demonstrator circuit where the bulb is glowing indicating the metallized core can successfully conduct electricity when it is connected to the circuit. This simple setup gives a visual prove that the electricity can flow through the deposited copper layer and it can be used for the application in mind.

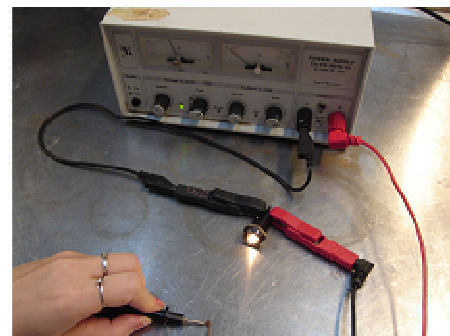


Figure 13: Demonstrator circuit built to test the selectively metallized on-off switch core.

Challenges for MIDs by 2k moulding

Main challenges of MID manufacturing by two component injection moulding and subsequent selective metallization is to achieve selective metallization on a micro scale and to metallize the through holes or blind holes with diameters in the micro range. In case of a strongly adhering material pair there exists an intermediate zone where molecules from both sides are diffused and mixed [3]. The width of this intermediate zone can be in the range of a few microns to several hundred microns. During the metallization of the plastic part, this intermediate zone is only partially metallized [3]. This partially metallized zone usually is not a problem when

the part size is big and feature dimensions are not below the millimeter range. But for micro scale selective metallization, this intermediate mixing zone is crucial and can hinder the selectivity of metallization [3].

Summary and Conclusion

MID production by two component injection moulding calls for modification in material, process and part design than the conventional 2k moulding. The polymer-polymer bond strength, polymer-polymer interface, material shot sequence and many other details need special consideration in case of MIDs for highly constrained and technically challenging applications [4]. For an example MID for micro application: a high surface area to volume ratio of micro products change the wettability, friction, adhesion and thermal interaction between the second shot polymer melt and the first shot substrate [4]. For micro MID, the interface quality between the two polymers is more important than the adhesion between two polymers. A polymer material having poor natural adhesion may not be suitable for macro products, but the same material combination can work well in two component micro moulding due to this size effect [4]. A large surface is in action compared to the part volume. More importantly selective metallization can be achieved due to the absence of interfacial mixing zone in case of a poorly adhering material pair [4].

The experimental work based on the MID concept of an on-off switch shows that the concept is feasible. Materials and metallization recipe can work together for selective metallization of micro scale MID. Although there is a concern about further down scaling and through hole metallization, a dedicated 2k moulding machine with rotating table and an optimized metallization set-up (like back and forth motion of the substrate or pressure driven chemical circulation during metallization) can meet the challenges.

Acknowledgements

The authors gratefully acknowledge financial support from Danish Ministry of Science and Innovation under the project "Selective micro metallization of polymers-(contract 61568)" and the co-operation of SONION Roskilde A/S. Support of COTECH project is also acknowledged.

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